УДК 536.242 DOI: https://doi.org/10.24028/gj.v45i4.286289

Development of the methodology of energy and environmental safety of Ukraine based on own geothermics

Y.P. Starodub, V.M. Karpenko, A.P. Havrys, D.A. Behen, 2023

Lviv State University of Life Safety, Lviv, Ukraine
Received 15 May 2023

The article presents an idea of the project that defines the development of a geothermal power plant methodology based on a single isolated well. It is planned to develop a technical and economic rationale and geological and geophysical aspects of the development of geothermal energy and to obtain data on deposits of geothermal water in the deep.

Extraction of heat from hot rocks at the pits is to be carried out using a special energy carrier, construction of the operating column, and circulation mode.

To create a model in the project, a well is needed with a depth of 4,702 m, temperature at the bottom of 130 °C, an unperforated casing string with a diameter of 245 mm to a depth of 4,500 m, and no formation fluids.

The transfer and transformation of the energy carrier by the working body into electric and hydrogen energy is maintained by ORC (Organic Rankine Cycle).

The development of the methodology includes two stages:

The first stage of the project involves legal preparation at the local and state levels for the use of the land plot and technical means of the drilled well and obtaining licenses and permits for the implementation of the project. It is planned to develop a technical and economic feasibility study for the construction of a geothermal electric station that will generate electricity and hydrogen energy for consumers.

The second stage of the project involves the technical preparation of the well for its use as part of a geothermal power station. Remediation of the well to a depth of 4,500 m is foreseen, as well as the implementation of industrial geophysical studies of the technical condition of the unperforated casing string; conducting preliminary geothermal studies on the stability and thermal productivity of hot rocks.

The authors intend to use results in the oil-and-gas industry, which has deep wells that have completed their purpose for hydrocarbon extraction, as well as in the nuclear, metallurgical, chemical, and many other fields.

Key words: digital ecological and technological model, consumer support, heat, electric energy.

Introduction. ***The current state of the problem of studying the geothermal state model of the Earth***. Let us consider the known energy balance of radiative exogenous and endogenous heat fluxes on the Earth's surface. The energy balance raises a number of questions [Karpenko et al., 2021].

The first, why is the endogenous heat flux (398.2 W/m^2) is higher than the exogenous one (340.4 W/m^2) according to publications [Buzan, Huber, 2020]?

The second is why we consider the known average heat flow associated with the conductive transfer of heat with a density of

Citation: *Starodub, Y.P., Karpenko, V.M., Havrys, A.P., & Behen, D.A.* (2023). Development of the methodology of energy and environmental safety of Ukraine based on own geothermics. *Geofizicheskiy Zhurnal*, *45*(4), 128—135. https://doi.org/10.24028/gj.v45i4.286289.

0.087 W/m^2 in the vertical direction according to the Fourier law between the horizontal surfaces of rocks? This makes the total power of the heat flow from the Earth's surface 4.42·10^{13} W [Pollak et al., 1993] (latest data: 4.7·10^{13} W [Davies, Davies, 2010; Beall et al., 2021]), which is well thought out. The main heat flow of heating-cooling of the Earth, if the average temperature on the Earth's surface has a value of 14.2 °C, and the stable temperature under the Earth's surface at a depth of 50 m has an average value of 10 °C [Guo et al., 2020; Lischenko, Kudrashov, 2021; He et al., 2021].

The third is where the stable power of the Earth's heat flow comes from, to heat the atmosphere according to the Stefan-Boltzmann law with medium and long infrared waves (IR waves) from a depth of 50 m, where the average temperature is about 10 °C, which corresponds to the density of the heat flow 364.46 W/m^2 and the total heat flow from the Earth's surface is 1.859·10^{17} W (for the average radius of the Earth [Zimmermann et al., 2000; Balázs et al., 2023])?

The fourth is why on the surface of the atmosphere, where the temperature is minus 18 °C, the power of cooling the Earth with IR waves is 1.23·10^{17} W (239.9 W/m^2) if the absorption of solar thermal energy of IR waves by the Earth's surface is at the level of 163.3 W/m^2 [Vogel et al., 2019]?

Fifth, why is the IR wavelength of cooling an order of magnitude longer than the IR wavelength of heating the Earth's surface by the Sun's rays?

Sixth — can the power of the decay of radioactive elements be the main source of heating the Earth, if it is twice smaller than even the conductive heat flux of 4.42·10^{13} W [Lay et al., 2008]? In other words, the power density (398.2 W/m^2) of radiant heat flow from the Earth's surface is 4500 times greater than the power density (0.087 W/m^2) of its conductive heating cooling, and at a depth of 50 m (364.46 W/m^2) — 4200 times.

Studies obtained parameters of the Earth's heat flows [Davies, Davies, 2010] and an example of the seasonally stable temperature of the Earth at a depth of 30 m in the local place [Sliwa, Rosen, 2015; Sliwa et al., 2021].

In the geothermal model of the «cold» Earth [Karpenko et al., 2021], the authors consider the temperature distribution in its depths. The process of cooling the Earth with radioactive sources of internal heat with a total power not exceeding half of 4.42·10^{13} W is considered as a conductive heat flow. In the model, the temperature in the center of the Earth is held constant during its evolution, about 6370 K.

The geophysical model of the «hot» Earth [Ahmed et al., 2022] tries to explain the conductive heat flow of the Earth by phase transformations of matter on the surface of the core. In the model, the initial temperature in the centre of the Earth is at the level of 30.000 K.

The well-known [Herndon, 2007] geophysical model of the «hot» Earth explains the conductive heat flow of the Earth by a georeactor located in the centre of the core. The temperature in the centre of the Earth is considered to be millions of degrees.

A similar opinion is expressed by [Luque et al., 2019; Starodub et al., 2020, 2022].

The well-known [Dai et al., 2019] concept of a source in the bowels of the Earth and planets is proven by geological and astrophysical facts. Vivid examples of the influence of the location of the Solar System in the Galaxy on the processes of thermal and geological activity of the Earth during its evolution are given.

The well-known geothermal model of the Earth with a conductive endogenous heat flow, considered in [Heymann, 2014], provides an estimate of the average thickness of the crust (45 km) during the Earth's existence.

Alongside the investigation of the territory's safety in the supply of pure thermic energy sphere is supported by the Lviv State University of Life Safety in cooperation with the Institute of Geophysics of National Academy of Sciences of Ukraine [Yemelyanenko et al., 2018; Popovych, Voloshchyshyn, 2019; Ivanusa et al., 2019]. Thus, the project is developed in close cooperation with the forementioned scientists.

Methods. Methodology with the considered innovations allows exploiting the geothermal resource of hot rocks of a deep well, isolated from formation fluids, with maximum efficiency, for the generation of thermal energy with subsequent conversion into electrical energy by the ORC system (Organic Rankine cycle) module with efficiency greater than 25 %, and further prospective transformation into hydrogen.

The project of a geothermal power station based on an isolated single well belongs to the civil security energy industry which allows the construction of autonomous, stable, ecologically and ergonomically safe power stations that generate heat, electricity and hydrogen energy for consumers using geothermal energy, namely heat of rocks compressed by gravity, opened at depth by a single well isolated from reservoir fluids. The project based on the proposed methodology can be used in the oil and gas industry which has deep wells no longer usable for hydrocarbon production, as well as in the nuclear, metallurgical, chemical, food, engineering industries in terms of efficient ORC, in the transport industry, in agriculture and animal husbandry in terms of use of autonomous heat, electricity, hydrogen energy.

The project has modern scientific and technical solutions of construction, regimes, materials for extraction, transportation, conversion of the enthalpy of hot rocks on the earth's surface into electric and hydrogen energy using ORC modules with an efficiency of more than 25 % which would make the technology commercially, socially, and energetically successful.

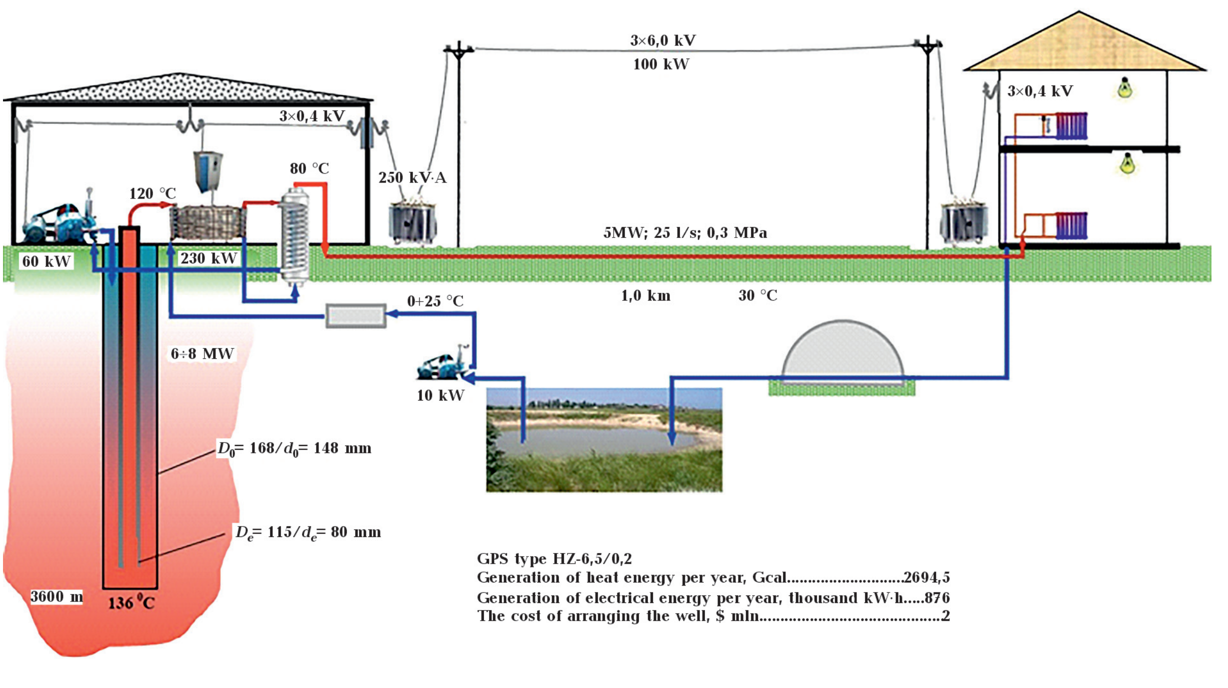
Extraction of heat from hot rocks in boreholes is performed with maximum efficiency by a special energy carrier, construction of the operating column, and circulation mode.

Transportation of thermal energy by a special energy carrier from the hole to the mouth is performed with minimal losses and maximum productivity of the circulation of the energy carrier in the well.

The transfer and transformation of the energy carrier by the working body into electric and hydrogen energy using the ORC module is performed with an efficiency of over 25 % in electric thermoenergy power plant.

In addition to scientific, educational, industrial, economic functions useful for the universities mentioned in the project, the station is scaled to the entire socio-economic infrastructure of the country.

To create a model in the project, a well was selected, drilled by a state-owned enterprise, with a temperature at the hole of 136 °C, with



The model presented with the electric generated capacity of 6 to 8 MW heating the building presented.

an unperforated casing string with a diameter of 148 mm to a depth of 3600 m, without reservoir fluids (see Figure).

On the figure scheme water pumped from the adjacent water reservoir (pond, river) moves into the deep well heated on the way down through the casing, then pumped up to the surface by motors fed by electricity obtained from ORC module nourishing the local settlement with heat and electricity. Cooled water is returned to the well again, the required amount is added from the water tank. Water fluid including necessary chemical ingredients heated moves upward without giving off the heat due to the low thermal permeability of the inner operating column.

The project provides for the first stage: legal preparation at the local and state levels for the use of the land plot and the ownership of the drilled well, a license for the use of subsoil without mining, permits for the use of surface and groundwater, certain types of construction and earthworks, contracts for the implementation of integration works for the unpromising exploratory well for oil and gas into the socio-economic infrastructure of the settlements adjacent to the well, on the basis of which it is planned to develop a feasibility study for the construction of an electric geothermal plant that will generate electric and hydrogen energy for consumers. The term of the first stage is one year.

The second stage of the project involves the technical preparation of the well for its use as part of a geothermal power station. It would include remediation of the well to a depth of 4.500 m and the implementation of industrial geophysical studies of the technical condition of the unperforated casing string; conducting preliminary geothermal studies on the stability and thermal productivity of hot rocks. The technical and economic justification is being clarified. A working technical project for the construction of the station is being developed.

Further work involves the construction of technological facilities; manufacturing, transportation, installation, start-up, and adjustment of the well and ground equipment of the station.

Research methodology. The geothermal power plant project based on an isolated single well belongs to the energy industry which builds autonomous, stable, ecologically and ergonomically safe power plants that generate heat, electricity and hydrogen energy for consumers using geothermal energy, namely, the heat of gravitationally compressed mountain rocks opened at depth by a single well isolated from reservoir fluids.

The project can be used in the oil and gas industry which has deep wells that have completed their purpose for hydrocarbon extraction, as well as in the nuclear, metallurgical, chemical, food, engineering industries in terms of effective ORC, in the agriculture and animal husbandry in terms of use of autonomous heat, electricity, and hydrogen energy.

The project presupposes modern scientific and technical solutions of structures elaborated in the project, regimes, materials for extraction, transportation, transformation of energy of hot rocks on the surface into electric and hydrogen energy using ORC modules with an efficiency of more than 25 %, which makes this technology commercially, socially, and energetically successful. Extraction of energy from hot rocks in boreholes is carried out with maximum efficiency using a special energy carrier and construction of the production column with a circulation mode.

Transportation of thermal energy by a special energy carrier from the hole to the mouth is performed with minimal losses and maximum productivity of the circulation of the energy carrier in the well.

Results. On the basis of the research, it is proposed to develop a technology for the development of geothermal energy. Approbation of the model is carried out on the pages of international scientific publications, and experimental studies of heat generation carried out on real deep wells. Studies have shown that the cost of 1 gcal of geothermal energy is 2—3 times less than the cost of 1 gcal when burning gas for the same costs of drilling wells up to 4.000 m deep.

Expected results of the project include:

a) description of scientific or technical products (if any) that will be created as a result of the project (indicating its expected qualitative and quantitative (technical) characteristics);

b) justification of the advantages of the expected scientific or scientific-technical products (if any) in comparison with the existing analogues;

c) substantiation of the practical value of the planned project results for the economy and society (for projects involving applied research and scientific and technical developments).

The scientific result of this project is the development for society of the thermodynamic potential characteristic of the thermodynamic system of selecting the main independent variables of entropy and pressure of the gravitational field of the geological environment (enthalpy) on its own territory. It is sufficient for the stable simple and extended reproduction of the social resource, quality and life expectancy through the production and consumption of natural energy without heating and polluting into the Earth's atmosphere.

Discussion and conclusions. The obtained scientific and technical results of the project are aimed at the development of:

– chemical industry to create new materials;

– machine-building technologies for the creation of new well equipment;

– mechanical engineering for the creation of new ground equipment;

– drilling equipment;

– technologies for remote sensing of the Earth's thermal field;

– legislation regarding the district location of the construction of geothermal stations and the use of geothermal waters;

– extraction of rare earth metals from underground brines;

– mining industry for extraction of rare earth metal;

– the metallurgical industry for the production of thermoelectric elements for the EGS-ISW technology (energy geothermal station on the basis of an isolated single well);

– investment processes in the energy sector of Ukraine;

– educational and scientific, research and design programs;

– description of ways and means of further use of project implementation results in public practice.

The scientific and technical product of this project is the developed scientific technology of efficient use of geothermal energy from deep rocks by a single well isolated from formation fluids, the average calorific value of which reaches 10 mW of thermal energy, which is equivalent to the productivity of a gas well of 26.6 thousand m^3/day. In the conclusion, the society of Ukraine will obtain knowledge about the two compared technologies for generating 1 gcal of thermal energy from the Earth's depths in different ways.

The well-known technology of providing socio-economic processes in Ukraine with thermal energy — the development of the final natural gas deposits of the Earth's subsoil consists of many consecutive stages, namely: the search is carried out with a probability of 35 % (every third well is successful) of a gas field, design, drilling, extraction, preparation, transportation, burning and receipt by the consumer of 1 gcal of thermal energy. The average productivity of a well with an average flow rate of 26.6 thousand m^3/day in Ukraine is 13—15 years, which is accompanied by annual costs for intensification of production and repair of the well. The new technology of providing social and economic processes in Ukraine with thermal energy — the development of inexhaustible ready-made thermal energy of the Earth's bowels consists of: remote sensing of the Earth's thermal field in an arbitrary given place, design, drilling, extraction, conversion into thermal, electric, hydrogen energy for consumption with a term generation for 50 years without intensification and capital repairs of wells.

The value of the planned results of technology implementation is as follows:

– unlimited in quantity for the development of infrastructure on the territory of Ukraine;

– ecologically clean;

– stable and inexhaustible;

– safe to use;

– autonomous;
– available to every consumer of Ukraine;
– generates heat, electricity, hydrogen, and oxygen, which is important for transport, chemical, agricultural industry, and the social sphere.

References

Ahmed, A.A., Assadi, M., Kalantar, A., Sliwa, T., & Sapińska-Śliwa, A. (2022). A critical review on the use of shallow geothermal energy systems for heating and cooling purposes. *Energies, 15*(12), 4281. https://doi.org/10.3390/en15124281.

Balázs, A., Gerya, T., May, D., & Tari, G. (2023). Contrasting transform and passive margin subsidence history and heat flow evolution: Insights from 3D thermo-mechanical modeling (Vol. 524, pp. SP524—2021). Geol. Soc., London, Spec. Publ. https://doi.org/10.1144/SP524- 2021-94.

Beall, A., Fagereng, Å., Davies, J.H., Garel, F., & Davies, D.R. (2021). Influence of subduction zone dynamics on interface shear stress and potential relationship with seismogenic behavior. *Geochemistry, Geophysics, Geosystems, 22*(2), e2020GC009267. https://doi.org/10.1029/2020GC009267.

Buzan, J.R., & Huber, M. (2020). Moist heat stress on a hotter Earth. *Annual Review of Earth and Planetary Sciences, 48*, 623—655.

Dai, F., Masuda, K., Winn, J.N., & Zeng, L. (2019). Homogeneous analysis of hot earths: Masses, sizes, and compositions. *The Astrophysical Journal, 883*(1), 79.https://doi.org/10.3847/1538-4357/ab3a3b.

Davies, J.H., & Davies, D.R. (2010). Earth's surface heat flux. *Solid Earth, 1*(1), 5—24, https://doi.org/10.5194/se-1-5-2010.

Guo, A., Yang, J., Sun, W., Xiao, X., Cecilia, J.X., Jin, C., & Li, X. (2020). Impact of urban morphology and landscape characteristics on spatiotemporal heterogeneity of land surface temperature. *Sustainable Cities and Society, 63*, 102443.https://doi.org/10.1016/j.scs.2020.102443.

He, B.J., Wang, J., Liu, H., & Ulpiani, G. (2021). Localized synergies between heat waves and urban heat islands: Implications on human thermal comfort and urban heat management. *Environmental Research, 193*, 110584. https://doi.org/10.1016/j.envres.2020.110584.

Herndon, J.M. (2007). Solar System processes underlying planetary formation, geodynamics, and the georeactor. In *Neutrino Geophysics: Proceedings of Neutrino Sciences 2005* (pp. 53—89). Springer New York. https://doi.org/10.1007/978-0-387-70771-6_6.

Heymann, Y. (2014). The dichotomous cosmology with a static material world and expanding luminous world. *Progress in Physics, 10*(3), 178—181.

Ivanusa, A., Yemelyanenko, S., Yakovchuk, R., & Ivanusa, Z. (2019). Safety-focused stakeholder management in civil protection projects. *International Scientific and Technical Conference on Computer Sciences and Information Technologies* (pp. 27—31). https://doi.org/10.1109/STC-CSIT.2018.8929847.

Karpenko, V., Starodub, Y., & Havrys, A. (2021). Computer Modeling in the Application to Geothermal Engineering. *Advances in Civil Engineering*, 6619991. https://doi.org/ 10.1155/2021/ 6619991.

Lay, T., Hernlund, J., & Buffett, B.A. (2008). Core-mantle boundary heat flow. *Nature Geoscience, 1*(1), 25—32. https://doi.org/10.1038/ngeo.2007.44.

Lischenko, L.P., & Kudrashov, O.I. (2021). The results of the studyof spatio-temporalchanges in surfacetemperaturesof Zaporizhya based on satellite data. *Ukrainian Journal of Remote Sensing, 8*(3), 27—36. https://doi.org/10.36023/ujrs.2021.8.3.198 (in Ukrainian).

Luque, R., Pallé, E., Kossakowski, D., Dreizler, S., Kemmer, J., Espinoza, N., ... & Wohler, B. (2019). Planetary system around the nearby M dwarf GJ 357 including a transiting, hot, Earth-sized planet optimal for atmospheric characterization. *Astronomy & Astrophysics, 628*, A39. https://doi.org/10.1051/0004-6361/201935801.

Pollack, H.N., Hurter, S.J., & Johnson, J.R. (1993). Heat flow from the Earth's interior: Analysis of the global data set. *Reviews of Geophysics, 31*(3), 267. https://doi.org/10.1029/93rg01249.

Popovych, V., & Voloshchyshyn, A. (2019). Environmental impact of devastated and scapes of Volynian Upland and Male Polisya (Ukraine). *Environmental Research, Engineering and Management, 75*(3), 33—45. https://doi.org/10.5755/j01.erem.75.3.23323.

Sliwa, T., Sapińska-Śliwa, A., Gonet, A., Kowalski, T., & Sojczyńska, A. (2021). Geothermal Boreholes in Poland — Overview of the Current State of Knowledge. *Energies, 14*(11), 3251. https://doi.org/10.3390/en14113251.

Sliwa, T., & Rosen, M.A. (2015). Natural and artificial methods for regeneration of heat resources for borehole heat exchangers to enhance the sustainability of underground thermal storages: A review. *Sustainability, 7*(10), 13104—13125. https://doi.org/10.3390/su71013104.

Starodub, Y., Karabyn, V., Havrys, A., Kovalchuk, V., Rogulia, A., & Yemelyanenko, S. (2022). Geophysical research in the pre-Carpathian hydrosphere situation forthe environmental civil protection purposes. *Geofizicheskiy Zhurnal, 44*(4), 171—182. https://doi.org/10.24028/gj.v44i4.264847.

Starodub, Y., Karpenko, V., Karabyn, V., & Shuryhin, V. (2020). Mathematical Modeling of the Earth Heat Processes for the Purposes of Eco-technology and Civil Safety. *IEEE 15th International Conference on Computer Sciences and Information Technologies (CSIT), Zbarazh, Ukraine* (pp. 146—149). https://doi.org/10.1109/CSIT49958.2020.9322009.

Vogel, M.M., Zscheischler, J., Wartenburger, R., Dee, D., & Seneviratne, S.I. (2019). Concurrent 2018 hot extremes across Northern Hemisphere due to human-induced climate change. *Earth's Future, 7*(7), 692—703. https://doi.org/10.1029/2019EF001189.

Yemelyanenko, S., Rudyk, Y., Kuzyk, A., & Yakovchuk, R. (2018). Geoinformational system of rescue services. *Paper presented at the MATEC Web of Conferences, 247*. https://doi.org/10.1051/matecconf/201824700030.

Zimmermann, L., Moritz, K., Kennel, M., & Bittersohl, J. (2000). Influence of bark beetle infestation on water quantity and quality in the Grosse Ohecatchment (Bavarian Forest National Park). *Silva Gabreta, 4*(5), 1—62. https://doi.org/10.1111/conl.12153.

Розроблення методології енергетичної, екологічної та продовольчої безпеки України на основі власних геотермальних ресурсів

Ю.П. Стародуб, В.М.Карпенко, А.П. Гаврись, Д.А. Беген, 2023

Львівський державний університет безпеки життєдіяльності, Львів, Україна

У статті розглянуто ідею проєкту, що визначає розробку методології геотермальної електростанції на основі однієї ізольованої свердловини. Планується розробити техніко-економічне обґрунтування, геолого-геофізичні аспекти розвитку геотермальної енергетики, отримати дані про поклади геотермальних вод на глибині. Відбір тепла від гарячих порід на вибоях передбачається здійснювати за допомогою спеціального енергоносія, конструкції робочої колони та режиму циркуляції. Для створення моделі — в проєкті свердловина завглибшки 4702 м, з температурою на забої 130 °C, з неперфорованою обсадною колоною діаметром 245 мм на глибину 4500 м, без пластових флюїдів. Передача і перетворення енергоносія робочим тілом в електричну і водневу енергію підтримується ORC (органічний цикл Ренкіна).

Діяльність з розробки методики включає два етапи. Перший передбачає правову підготовку на місцевому та державному рівнях щодо використання земельної ділянки й технічних засобів пробуреної свердловини, отримання ліцензій та дозволів на реалізацію проєкту. Планується розробка техніко-економічного обґрунтування будівництва геотермальної електростанції, яка вироблятиме електроенергію та водневу енергію для споживачів.

На другому етапі проєкту свердловина має бути технічно підготовлена до використання її у складі геотермальної електростанції. Передбачено рекультивацію свердловини завглибшки 4500 м, виконання промислово-геофізичних досліджень технічного стану неперфорованої обсадної колони; а також попередніх геотермічних досліджень на стійкість і теплопродуктивність гарячих порід.

Автори мають намір отримані результати використовувати в нафтогазовій промисловості, де є глибокі свердловини, що відпрацювали своє призначення для видобутку вуглеводнів, а також в атомній, металургійній, хімічній та багатьох інших галузях.

Ключові слова: цифрова еколого-технологічна модель, забезпечення споживачів, тепло, електроенергія.